

## CLAIMS

We claim:

- [c1]            1.        A flow control valve for providing a substantially constant flow of fluid through the valve, comprising:
- a valve body having an inlet, an outlet, a flow passageway coupling the inlet to the outlet, and a cavity intersecting the flow passageway;
  - a hollow piston movably disposed in the cavity adjacent to the flow passageway;
  - a seal positioned in the cavity proximate to the piston and sealably separating the cavity into first and second chambers, the seal having at least a section exposed to the fluid in the first chamber, the section of the seal defining a first effective inner area within the hollow piston;
  - a biasing member configured to urge the hollow piston;
  - a reference pressure passageway in fluid communication with the inlet and the second chamber; and
  - a member positioned at least proximate to the piston and the flow passageway, the member having an orifice with a second inner effective area at least approximately equal to the first effective inner area defined by the section of the seal, the piston being movable relative to the member to vary a portion of the flow passageway.
- [c2]            2.        The valve of claim 1 wherein the hollow piston includes a head configured to contact the seal and a sleeve projecting from the head, the sleeve having an end portion adjacent to the member.

- [c3]           3.     The valve of claim 1 wherein the hollow piston, the seal, and the biasing member form internal components of the valve, and wherein the internal components are removable as a unit.
- [c4]           4.     The valve of claim 1 wherein the seal is a diaphragm seal having central and perimeter portions coupled to the valve body and an annular portion between the central and perimeter portions, the annular portion being positioned to contact a portion of the hollow piston.
- [c5]           5.     The valve of claim 1 wherein the piston includes a head, and wherein the seal is a diaphragm seal having a first convolution radially outside the head and a second convolution radially inside the head.
- [c6]           6.     The valve of claim 1 wherein the seal is a first seal between the valve body and hollow piston radially inside of the piston, and wherein the valve further comprises a second seal between the valve body and the hollow piston radially outside of the piston.
- [c7]           7.     The valve of claim 1 wherein the hollow piston includes a sleeve with an end portion projecting radially inward.
- [c8]           8.     The valve of claim 1 wherein the inlet is exposed to the fluid under a first pressure and the outlet is exposed to the fluid under a second pressure, the valve body, the piston, the seal, the biasing member, and the member being sized and configured to provide a fluid flow through the flow passageway with a substantially constant flow rate independent of fluctuations in the second pressure at the outlet.

- [c9]            9.     The valve of claim 1 wherein the biasing member is a coiled spring.
- [c10]           10.    The valve of claim 1 wherein the biasing member is configured to urge the hollow piston in a first direction, and wherein the valve further comprises a guide post disposed at least partially in the cavity and configured to reduce movement of the piston in a second direction transverse to the first direction.
- [c11]           11.    The valve of claim 1 wherein the hollow piston includes a head positioned to contact the seal and a sleeve projecting from the head, the sleeve having a first portion with a first diameter and a second portion with a second diameter different than the first diameter, the second portion being sized and positioned so that at least a section of the second portion is movable within the orifice of the member throughout at least a portion of a stroke of the piston.
- [c12]           12.    The valve of claim 11 wherein the first portion of the sleeve is between the head and the second portion of the sleeve, wherein the first diameter is greater than the second diameter, and wherein the valve further comprises at least one stop attached to the member to limit the range of motion of the piston.
- [c13]           13.    The valve of claim 11 wherein the second portion is sized and positioned so that the at least a section of the second portion is movable within the orifice of the member throughout the stroke of the piston.
- [c14]           14.    The valve of claim 1 wherein the hollow piston includes a head positioned to contact the seal and a sleeve projecting from the head, the sleeve having a first portion with a first diameter and a second portion with a second diameter different than the first diameter, the second portion having a plurality of legs defining openings through which fluid flows.

[c15] 15. The valve of claim 14 wherein the piston is movable along an axis, and wherein the individual legs have a proximal portion with a first dimension transverse to the axis and a distal portion with a second dimension transverse to the axis, the second dimension being less than the first dimension to reduce the rate at which the area of the openings decreases as the valve closes.

[c16] 16. The valve of claim 1 wherein the reference pressure passageway includes a restriction to limit the fluid flow rate between the second chamber and the inlet.

[c17] 17. A flow control valve for providing a substantially constant flow of fluid through the valve, comprising:

- a valve body having an inlet, an outlet, a flow passageway coupling the inlet to the outlet, and a cavity intersecting the flow passageway;
- a hollow piston movably disposed within the cavity;
- a seal separating the cavity into first and second chambers, the second chamber having a generally annular configuration with an effective inner diameter;
- a biasing member configured to urge the hollow piston toward the second chamber;
- a reference pressure passageway in fluid communication with the inlet and the second chamber; and
- a piston seat positioned at least proximate to the piston and the flow passageway, the piston seat having an effective inner diameter at least approximately equal to the effective inner diameter of the second chamber.

[c18] 18. The valve of claim 17 wherein the seal is a diaphragm seal having center and perimeter portions coupled to the valve body and an annular portion between the center and perimeter portions positioned to contact the hollow piston.

- [c19]            19.    The valve of claim 17 wherein the seal includes a first convolution radially outside the piston and a second convolution radially inside the piston.
- [c20]            20.    The valve of claim 17 wherein the seal includes a first seal between the valve body and the hollow piston radially outside of the piston, and wherein the valve further comprises a second seal between the valve body and the hollow piston radially inside of the piston.
- [c21]            21.    The valve of claim 17 wherein the hollow piston includes a head adjacent to the seal and a sleeve projecting from the head, the sleeve having an end portion adjacent to the piston seat.
- [c22]            22.    The valve of claim 17 wherein the hollow piston, the seal, and the biasing member form internal components of the valve, and wherein the internal components are removable as a unit.
- [c23]            23.    The valve of claim 17 wherein the inlet is exposed to the fluid under a first pressure and the outlet is exposed to the fluid under a second pressure, the valve body, the piston, the seal, the biasing member, and the piston seat being sized and configured to provide a fluid flow through the flow passageway with a substantially constant flow rate independent of fluctuations in the second pressure at the outlet.
- [c24]            24.    The valve of claim 17 wherein the hollow piston includes a head positioned to contact the seal and a sleeve projecting from the head, the sleeve having a first portion with a first diameter and a second portion with a second diameter different than the first diameter, the second portion being sized and positioned so that at least a section of the second portion is movable within the piston seat throughout at least a portion of a stroke of the piston.

[c25] 25. The valve of claim 24 wherein the first portion of the sleeve is between the head and the second portion of the sleeve, wherein the first diameter is greater than the second diameter, and wherein the valve further comprises at least one stop attached to the piston seat to limit the range of motion of the piston.

[c26] 26. The valve of claim 24 wherein the second portion is sized and positioned so that the at least a section of the second portion is movable within the piston seat throughout the stroke of the piston.

[c27] 27. The valve of claim 17 wherein the hollow piston includes a head positioned to contact the seal and a sleeve projecting from the head, the sleeve having a first portion with a first diameter and a second portion with a second diameter different than the first diameter, the second portion having a plurality of legs defining openings through which fluid flows.

[c28] 28. The valve of claim 27 wherein the piston is movable along an axis, and wherein the individual legs have a proximal portion with a first dimension transverse to the axis and a distal portion with a second dimension transverse to the axis, the second dimension being less than the first dimension to reduce the rate at which the area of the openings decreases as the valve closes.

[c29] 29. The valve of claim 17 wherein the reference pressure passageway includes a restriction to limit the fluid flow rate between the second chamber and the inlet.

[c30] 30. A flow control valve, comprising:  
a valve body having an inlet, an outlet, a flow passageway coupling the inlet to the outlet, and a cavity intersecting the flow passageway, the cavity having a first chamber and a second chamber;  
a hollow piston disposed within the first chamber;

a diaphragm seal configured to engage the piston, the diaphragm seal having a first convolution radially outside the piston and a second convolution radially inside the piston, the second convolution having a midpoint circumscribing a first effective inner area, the diaphragm seal separating the first and second chambers;

a biasing member configured to urge the hollow piston toward the second chamber;

a reference pressure passageway in fluid communication with the inlet and the second chamber; and

a piston seat positioned at least proximate to the piston, the piston seat surrounding a second effective inner area at least approximately equal to the first effective inner area.

[c31] 31. The valve of claim 30 wherein the hollow piston, the seal, and the biasing member form internal components of the valve, and wherein the internal components are removable as a unit.

[c32] 32. The valve of claim 30 wherein the hollow piston includes a head adjacent to the seal and a sleeve projecting from the head, the sleeve having an end portion adjacent to the piston seat.

[c33] 33. The valve of claim 30 wherein the inlet is exposed to the fluid under a first pressure and the outlet is exposed to the fluid under a second pressure, the valve body, the piston, the seal, the biasing member, and the piston seat being sized and configured to provide a fluid flow through the flow passageway with a substantially constant flow rate independent of fluctuations in the second pressure at the outlet.

[c34] 34. The valve of claim 30 wherein the hollow piston includes a head positioned to contact the seal and a sleeve projecting from the head, the sleeve

having a first portion with a first diameter and a second portion with a second diameter different than the first diameter, the second portion being sized and positioned so that at least a section of the second portion is movable within the piston seat throughout at least a portion of a stroke of the piston.

[c35]            35.    The valve of claim 34 wherein the first portion of the sleeve is between the head and the second portion of the sleeve, wherein the first diameter is greater than the second diameter, and wherein the valve further comprises at least one stop attached to the piston seat to limit the range of motion of the piston.

[c36]            36.    The valve of claim 34 wherein the second portion is sized and positioned so that the at least a section of the second portion is movable within the piston seat throughout the stroke of the piston.

[c37]            37.    The valve of claim 30 wherein the hollow piston includes a head positioned to contact the seal and a sleeve projecting from the head, the sleeve having a first portion with a first diameter and a second portion with a second diameter different than the first diameter, the second portion having a plurality of legs defining openings through which fluid flows.

[c38]            38.    The valve of claim 37 wherein the piston is movable along an axis, and wherein the individual legs have a proximal portion with a first dimension transverse to the axis and a distal portion with a second dimension transverse to the axis, the second dimension being less than the first dimension to reduce the rate at which the area of the openings decreases as the valve closes.

[c39]            39.    The valve of claim 30 wherein the reference pressure passageway includes a restriction to limit the fluid flow rate between the second chamber and the inlet.



[c40] 40. A flow control valve for providing a substantially constant flow of fluid through the valve, comprising:

a valve body having an inlet, an outlet, a flow passageway coupling the inlet to the outlet, and a cavity intersecting the flow passageway;

a hollow piston;

a diaphragm seal having a perimeter portion, a central portion, and an annular portion between the perimeter and central portions, the annular portion having an effective inner diameter, the diaphragm seal separating the cavity into a first chamber and a second chamber, the hollow piston being disposed in the first chamber at least proximate to the annular portion;

a biasing member configured to urge the hollow piston toward the second chamber;

a reference pressure passageway in fluid communication with the inlet and the second chamber; and

a piston seat configured to selectively engage the hollow piston, the piston seat having an effective inner diameter at least approximately equal to the effective inner diameter of the annular portion of the diaphragm seal.

[c41] 41. The valve of claim 40 wherein the annular portion of the diaphragm seal comprises a first convolution radially outside the hollow piston and a second convolution radially inside the piston.

[c42] 42. The valve of claim 40 wherein the hollow piston includes a head adjacent to the seal and a sleeve projecting from the head, the sleeve having an end portion adjacent to the piston seat.

[c43] 43. The valve of claim 40 wherein the hollow piston, the seal, and the biasing member form internal components of the valve, and wherein the internal components are removable as a unit.

[c44] 44. The valve of claim 40 wherein the inlet is exposed to the fluid under a first pressure and the outlet is exposed to the fluid under a second pressure, the valve body, the piston, the seal, the biasing member, and the piston seat being sized and configured to provide a fluid flow through the flow passageway with a substantially constant flow rate independent of fluctuations in the second pressure at the outlet.

[c45] 45. The valve of claim 40 wherein the hollow piston includes a head positioned to contact the seal and a sleeve projecting from the head, the sleeve having a first portion with a first diameter and a second portion with a second diameter different than the first diameter, the second portion being sized and positioned so that at least a section of the second portion is movable within the piston seat throughout at least a portion of a stroke of the piston.

[c46] 46. The valve of claim 45 wherein the first portion of the sleeve is between the head and the second portion of the sleeve, wherein the first diameter is greater than the second diameter, and wherein the valve further comprises at least one stop attached to the piston seat to limit the range of motion of the piston.

[c47] 47. The valve of claim 45 wherein the second portion is sized and positioned so that the at least a section of the second portion is movable within the piston seat throughout the stroke of the piston.

[c48] 48. The valve of claim 40 wherein the hollow piston includes a head positioned to contact the seal and a sleeve projecting from the head, the sleeve having a first portion with a first diameter and a second portion with a second

diameter different than the first diameter, the second portion having a plurality of legs defining openings through which fluid flows.

[c49] 49. The valve of claim 48 wherein the piston is movable along an axis, and wherein the individual legs have a proximal portion with a first dimension transverse to the axis and a distal portion with a second dimension transverse to the axis, the second dimension being less than the first dimension to reduce the rate at which the area of the openings decreases as the valve closes.

[c50] 50. The valve of claim 40 wherein the reference pressure passageway includes a restriction to limit the fluid flow rate between the second chamber and the inlet.

[c51] 51. A valve, comprising:  
a valve body having an inlet, an outlet, a flow passageway coupling the inlet to the outlet, and a cavity intersecting the flow passageway, the cavity having a first chamber and a second chamber, the second chamber having a generally hollow configuration;  
a piston assembly including a hollow piston body, a support member coupled to the hollow piston body, and a poppet coupled to the support member, the hollow piston body being disposed in the second chamber, the support member and the poppet being disposed in the first chamber;  
a seal having a hollow section separating the first and second chambers, the hollow section having a first effective inner area;  
a biasing member configured to urge the hollow piston body toward the first chamber;  
a reference pressure passageway in fluid communication with the outlet and the second chamber; and

a piston seat positioned to selectively engage the poppet, the piston seat enclosing a second effective inner area at least approximately equal to the first effective inner area.

[c52] 52. The valve of claim 51 wherein the seal is a diaphragm seal having central and perimeter portions coupled to the valve body and an annular portion between the central and perimeter portions positioned to contact the hollow piston body.

[c53] 53. The valve of claim 51 wherein the seal is a diaphragm seal coupled to the valve body and configured to engage the hollow piston body, the diaphragm seal having a first convolution radially outside the hollow piston body and a second convolution radially inside the hollow piston body.

[c54] 54. The valve of claim 51 wherein the hollow piston body has a generally annular configuration.

[c55] 55. The valve of claim 51 wherein the seal includes a first seal between the outside of the hollow piston body and the valve body, and wherein the valve further comprises a second seal between the inside of the hollow piston body and the valve body.

[c56] 56. The valve of claim 51 wherein the reference pressure passageway includes a restriction to limit the fluid flow rate between the second chamber and the outlet.